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Protection of Workers and Third Parties during the Construction of Linear Structures

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Abstract. The minimization of risk in the workplace through a focus on occupational health and safety (OHS) is one of the primary objectives for every construction project. The most serious accidents in the construction industry occur during work on earthworks and linear structures. The character of such structures places them among those posing the greatest threat to the public (referred to as “third parties”). They can be characterized as large structures whose construction may involve the building site extending in a narrow lane alongside previously constructed objects currently in use by the public. Linear structures are often directly connected to existing objects or buildings, making it impossible to guard the whole construction site. However, many OHS problems related to linear structures can be prevented during the design stage. The aim of this article is to introduce a new methodology which has been implemented into a computer program that deals with safety measures at construction sites where work is performed on linear structures. Based on existing experience with the design of such structures and their execution and supervision by safety coordinators, the basic types of linear structures, their location in the terrain, the conditions present during their execution and other marginal conditions and influences were modelled. Basic safety information has been assigned to this elementary information, which is strictly necessary for the construction process. The safety provisions can be grouped according to type, e.g. technical, organizational and other necessary documentation, or into sets of provisions concerning areas such as construction site safety, transport safety, earthworks safety, etc. The selection of the given provisions takes place using multiple criteria. The aim of creating this program is to provide a practical tool for designers, contractors and construction companies. The model can contribute to the sufficient awareness of these participants about technical and organizational provisions that can help them to meet workplace safety requirements. The software for the selection of safety provisions also contains module that can calculate necessary cost estimates using a calculation formula chosen by the user. All software data conform to European standards harmonized for the Czech Republic.

1. Introduction

The construction industry is one of the most critical areas of industry when it comes to injury statistics. Many articles have been presented about occupational safety in the construction industry. The authors of one paper presented a review summarizing the effectiveness of measures taken to prevent all types of occupational injuries arising during construction work, [1]. Another paper concluded that the human factor has been identified as a major contributor to OSH issues in the construction industry [2]. Another



study concluded that the relationship between safety and operational effectiveness is a result of the routines used to manage what should be a shared space [3]. There are not many contributions which deal directly with safety issues concerning linear structures. One of them is an article [4] in which the authors describe the safety management strategy during the construction of a bridge. In another article, the authors analyze injuries and safety measures during concreting at construction sites [5]. The authors of [6] presented an article which described how safety measures could affect the prices quoted for a project during the public procurement procedure, and also the length of the construction process. Many articles also deal with the psychological aspects of the behavior of workers at construction sites [7]. In paper [8], the authors presented the measurement of safety performance in road structures via behavioral observation.

When monitoring the progress of work and the risks occurring at selected construction sites it was concluded that the sites where injuries occur most frequently and are the most serious are those involving work on linear structures. Such sites also pose the greatest danger to members of the public (referred to as “third parties”) with regard to their nature, which can be defined as:

- large construction sites occupying a narrow strip that extends past existing structures
- work takes place while the adjoining area is in use by the public
- direct connection of the site with existing buildings and infrastructure
- the impossibility of guarding the whole construction site

The area of construction site safety focuses on various kinds of performed work according to their general nature (earthworks, work above the surface of a body of water) but not on safety issues at linear structures as a whole. With linear structures, many problems can be avoided right away at the structural design stage, though this depends on the degree of informedness about the given process. Advantageous use can be made of modern information technology during the preparation of safety measures to be implemented during construction, [9].

Safety at linear constructions is still insufficient mainly due to the low pricing of tenders, but also to time pressures when designing these measures. When trying to choose a quality contractor of construction work that is interested in executing the building project in question safely, it is imperative to be able to judge whether the price they state is really a price that would allow them to perform high quality, safe (and of course economical) construction work. In order to be able to set the expected bid price correctly it is necessary for the building project to be well designed. This includes the organizing principles behind the construction process and a bill of quantities composed so as to include all of the auxiliary structures without which the construction could not be realized safely. The contractor's bid reflects their attitude towards safety during the realization of construction work. Both the client and the contractor should share an interest in the production of an economical structure and simultaneously in the creation of a safe workplace both for the employees and for third parties moving around the construction site. As in the majority of cases the client is a lay person who has no idea about the safety issues involved in construction, they typically choose the contractor that offers the lowest bid. The correct procedure is for the designer to warn the contractor about what needs to be included in the bill of quantities in order to ensure the safe realization of construction work. This article describes a software-based approach that defines a decision-making and planning procedure that ensures construction work will be carried out with the maximum level of safety.

2. Software-based methodology

2.1. The nature of linear constructions

In the presented research, we focus on an area of construction where safety is influenced not only by the location of the site, its extent, and the influence of its surroundings, but also by geological conditions, the seasons, and other factors. No two linear structures are alike; every construction site is subject to a unique combination of factors. Different measures are necessary to ensure occupational safety in populated areas and in non-urban terrain. The procedures for machine and manual work are also

completely different. They even vary depending on the machines used. The geology of the investigated locality is important as well. Diverse methods are needed for excavations in cohesive or non-cohesive materials, and there is also the time aspect. In addition, it is necessary to consider the varying behavior of workers when it rains, if it is freezing cold, or in strong wind, for example.

It is also very important that, unlike buildings, linear structures can be a source of great risk to third parties. This is a serious problem, as safety at construction sites is evaluated only generally. There is no special approach to issues specifically concerning linear structures despite the fact that the volume and quantity of projects involving the realization of linear structures exceeds the volume of work involved in the construction of buildings.

If an excavated trench along the edge of a road is insufficiently barricaded off, pedestrians or even motorized vehicles can fall into it. Also, surrounding objects may cause the sides of the trench to collapse. At the same time, there is a high risk that the health of construction workers might be endangered.

Occupational health and safety (OHS) is one of the most underestimated aspects of construction projects involving linear structures. This is particularly due to the large scope of the safety measures needed, and thus also the high cost entailed. For example, 100 m of fencing might be sufficient for a typical construction site, but in the case of a linear structure the fence can extend for several hundreds of meters, or even several kilometers. Pedestrians moving in the area around a construction site can be protected by diverting the path outside the site or by creating a safe corridor around it. However, in the case of linear structures, pedestrians may even have to pass through the construction site. In this case, safe passageways through the site must be created and crossings over excavations or obstacles must be provided via footbridges or bridges.

Another issue is the need to secure the excavation against soil slides which could result in the burying and consequent death of a worker in the trench. The provision of support to the vertical walls of trenches is often underestimated, especially in the case of machine excavations. The cohesion of the earth changes over the course of time depending on outside conditions, and thus it is necessary to check the state of the walls, ditches, supports as well as access points before workers enter the trench. It is also necessary to prevent overloading of the edges of the trench up to the border of the shear wedge. The burial of workers in earth when executing excavation works is considered an occupational accident where the probability of survival is very low.

This is why it is necessary to draw people's attention to how to approach security measures at construction sites for linear structures, and to offer the possibility of defining safety requirements as early as during the design period, as well as during the period when a bid is being processed and subsequently during preparations for the realization of the linear structure. All of these options are possible using the software tool BOZPiS 1.0 [10], developed at Brno University of Technology's Faculty of Civil Engineering. The following chapters present the operating principles and components of this software, which is available online on the author's web page, which also has information on licence conditions.

2.2. Input data

The input data for the calculation consist mainly of information from the given order. These data can include information from documentation produced during the design phase or assembled for the tender procedure. Figure 1 shows the basic program environment. Using this window, the first basic module of the program "Requirements for securing the construction site" can be accessed. The program is able to include more functional models and can be extended. It is also possible to sign in to the user interface on this screen. After opening the module, the basic parameters are entered by choosing from the options offered. This part is suitable mainly for project administrators, allowing them to eliminate discovered problems in time and adjust the project in such a way that the safety risks are minimized, i.e. to redesign or move the route of a pipeline away from a road, etc.

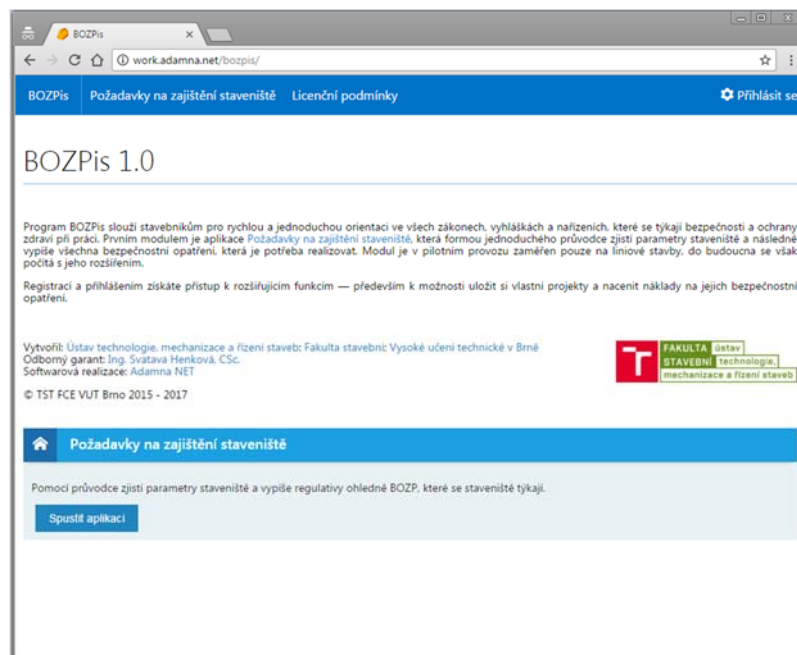


Figure 1. Basic program environment

Based on experience from the design of construction sites, their realization and the specific supervision of the safety coordinator, we selected basic types of linear structures, their placement in the terrain, the conditions present at the site and other influences. The program environment can be seen in Figure 2. The editable fields of the input influences are marked in green. The following input influences have to be entered into the program:

- Type of structure
- Type of territory
- Depth of excavation
- Excavated material
- Material of the laid pipeline
- Work near the surface of a body of water
- Work in the vicinity of live parts of electrical devices
- Work on a gas pipeline
- Work on microtunnelling.

2.3. Algorithm of the software

The software has been developed as a web-based application involving the PHP scripting language and the MySQL database system. Both technologies are well known for their performance and open nature. The website platform offers many benefits compared to common standalone applications – the application starts running instantly without the need for installation, users are not obliged to worry about updates, and it works on all devices across all operating systems. The only disadvantage of web-based applications is the requirement for internet connection during usage of the software. Today, mobile data has become widely used and operating costs for mobile data have become low, meaning this disadvantage has been outweighed by the benefits and can be considered a negligible handicap.

The screenshot shows a web browser window with the URL 'workadamna.net/bozpis/regulations/#'. The page has a blue header with navigation links: 'BOZPis', 'Požadavky na zajištění staveniště', and 'Licenční podmínky'. A 'Přihlásit se' button is in the top right. The main content area is titled 'Parametry staveniště' and contains a grid of green boxes, each representing a parameter with a current value and a 'změnit' (change) button.

Parameter	Current Value	Action
Druh stavby	Novostavba	změnit
Typ území	Zastavěné území	změnit
Hloubka výkopu	do 2.0 m	změnit
Materiál výkopu	zemina	změnit
Materiál ukládaného potrubí	plast	změnit
Práce v blízkosti vodní hladiny	ne	změnit
Práce v blízkosti živých částí el. zařízení	ne	změnit
Práce na plynovém potrubí	ano	změnit
Protlaky a mikrotunelování	ne	změnit

Figure 2. Input of the basic parameters of the construction site

The inner algorithm is based on a two-level logical function approach. This method makes it clear and simple to use for both software users and administrators, who fill the database of regulations. The two levels of logical conditions were introduced in order to keep the conditional rules as simple as possible. Each group of regulations usually has a particular condition which is relevant for all regulations belonging to this group. For example, all the regulations relevant to electricity are conditional on the presence of electric power lines in the area concerned. Since some regulations are only valid in some special cases (e.g. the voltage of power lines is too high, or the excavation is too deep), an individual condition can also be specified for a particular regulation.

When the algorithm is going through the database, the regulations are filtered according to the group-based logical conditions first, and then the item-based logical conditions are evaluated. Since the logical conditions are evaluated instantly while the questions are being answered at the beginning, the number of required questions can be adjusted during the process. It means that sometimes not all the questions are asked if they will not influence the result any more.

The logical condition is a logical expression linked to the questions which are asked at the beginning of the filtering procedure. The AND, OR and grouping operators (parenthesis) are allowed. Figure 3 displays an example of such logical conditions.

*The type of area IS **built-up area***
*AND the deepness of excavation IS **less than 1.3m***
*OR the deepness of excavation IS **less than 2.0 m***

Figure 3. Example of a logical conditions

The bolded parts of this logical expression are the questions asked at the start of the application, and the bold parts are the options offered as the answers to the questions. Using a combination of these expressions with logical AND, OR operators allows the description of any condition with which the regulation is linked.

Such approach makes this system very universal and flexible, and makes it able to be extended also to other types of constructions, since questions, answers and regulations described with logical conditions can be added or modified from the administration area.

3. Results and discussions

After entering all input data for the construction site, a list of regulations which need to be carried out at the construction site is displayed automatically. Regulations can be grouped according to the type of measure:

- Technical measures
- Organizational measures
- Documentation

We have assigned safety measures requiring unconditional obedience to this basic information. The given information is sorted with the help of an algorithm (at a specific place, at a given time). Figure 3 shows another possible way of sorting the measures according to groups such as construction sites, transport, etc. The user can switch between the displayed information as needed. If the user clicks on the blue title the whole section is hidden, which is advantageous if he or she only wants to print a certain part. In the case of some regulations, it is also possible to view an attached picture showing what the measure should look like. The working environment for the registration is also visible here. The name of the project can be entered and the project saved in the bottom right floating window.

The program presented above featuring a choice of safety measures is linked to a part which works out the needed costs with the aid of individual calculations supplied by a given construction contractor. Figure 4 shows how the calculation of the safety measures is entered according to individual categories and the determination of costs. It is necessary to be registered and to agree to the licence conditions in order to make use of this function; however, the software is provided completely free of charge.

Figure 4. Lists of safety measures and requirements, and the window for saving the project

The user can return to this calculation at any time using the “My project” tab and compare the expected costs of safety measures retrospectively. This part is already very useful when processing a bid

during the tender process. After this has been done, it is possible to compare the expected cost of safety measures with reality and adapt the calculations for further use, as shows Figure 5.

TECHNICKÉ POŽADAVKY			
Staveniště, zajištění staveniště			
Zajištění proti vstupu na staveniště zábradlím (splňujícím pevnostní požadavky) umístěným na hraně výkopu	2000	meters	500000
Zajištění proti vstupu na staveniště zábradlím (u něhož nemusí být splněny pevnostní požadavky) umístěným 1.5m od hrany výkopu	150	meters	22500
Označení staveniště proti vstupu nepovolanců bezpečnostním značením	20	pcs	3000
Označení stavby na viditelném místě	2	pcs	1500
Zbudování zařízení staveniště a skládek dle projektu ZOV	50	m2	3500
Udržování pořádku na staveništi	3600	hrs	250
Vybavení staveniště lékárníčkou, hasicími přístroji a havarijními soupravami	2	pcs	1500
Doprava a skladování			
Dodržení bezpečných vzdáleností dopravních prostředků a skládek materiálu od energetických zařízení (ochranná pásma)	Počet MJ	MJ	Cena / MJ
Používání zvukových signálů, zejména při couvání dopravních prostředků	Počet MJ	MJ	Cena / MJ
Vytýčení míst určených pro skladování na stavbě, jejich zajištění	Počet MJ	MJ	Cena / MJ

Projekt

Case Study No. 1

Celkem: 1606000 Kč

Změnit název

+ Uložit nový

Figure 5. The environment in which individual calculations take place

4. Conclusions

As has already been mentioned above, the approach focuses primarily on linear structures, though the software can be extended with other modules. Even though there are a great many as-yet unresolved situations concerning safety measures in the area of linear structures, the software, which is an application of the presented approach, can be used as a base for further extension. The simplest adaptation would be a modification for the construction of roads, but the software can be adapted to the construction of other building structures.

The program is free and its aim is not only to provide aid to designers and construction firms, but also to give clients an alternative to choosing between bids offered by contractors on the basis of lowest price. It enables users to select a bid that is right for their project, i.e. one that takes into account all aspects of the construction process and includes both economic factors and the necessary safety requirements. Not just the contractor but also the contracting authority is responsible for the safe realization of construction work, and they have the opportunity to influence the selection of a quality contractor in such a way that the result of their cooperation is a high-quality, safe and economical construction site. The greatest potential of the program presented in this article lies in the target group which it focuses on. These are the clients, designers as well as the contractors involved in construction work. It is intuitive and user-friendly.

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